Modeling United States Energy Consumption

1970 – 2040

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Abstract: This study quantifies the degree to which energy consumption is influenced by population, personal income, fuel prices, weather, and energy efficiency, and demonstrates that future demand growth is likely to be more moderate than is generally expected. Utilizing multiple regression of historical data from across the United States from 1970 to 2013, we modeled state-level energy consumption in the commercial, industrial, residential, and transportation sectors to estimate the total energy demand in each state and for the United States as a whole. Our results indicate that energy consumption will grow in some states and decline in others yielding moderate energy consumption growth for the United States as a whole. Due to the lack of state-specific energy consumption forecasts from the Energy Information Administration, and general tendency for simpler extrapolation methods used by many state governments to overestimate demand, we offer this model to help guide government policy makers and businesses in making decisions on future energy consumption.

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Introduction

Forecasting future energy requirements for public policy makers is necessary for infrastructure development, financial planning, and estimating the potential environmental impacts of energy use. A common method used by state policy makers to project future energy demand is to perform a simple linear extrapolation of historical energy demand against time; however, as we will demonstrate, this method will—for most states—severely over-estimate future demand due to increasing energy efficiency and decreasing energy intensity of the economies in most states. Furthermore, this method fails to take into account the interdependence of energy demand and economic activity, fuel prices, population growth, and climate. Inaccurate energy demand models weaken public policy, could lead to costly expenditures on unnecessary energy infrastructure, and risk overestimating the efficacy of public policies designed to mitigate energy use or pollution.

In Figure 1 below, the historical energy use for the United States is plotted in black against linear extrapolations of energy demand based on different periods of time. Total energy demand grew at an average annual rate of 4.3 percent during the 1960's and 2.2 percent during the 1970's. However, the growth rate was as low as 0.66 percent from the year 2000. Estimation of future energy demand growth based on an extrapolation from 1960 to 2013 would yield a projected increase of 17 percent by 2030, whereas an extrapolation from 2005 would yield a decrease of 7 percent. Similarly, in Figure 2 below, the annual growth rate of energy use is plotted versus a linear fit and a linear fit with 95 percent confidence intervals of the annual growth rates. As with Figure 1, this graphic illustrates that the general trend of energy demand growth is negative.

In both graphics, key events that suppressed demand growth are visible, including the Oil Crisis of the 1970's, the 1980's recession, and the 2009 recession, which suggests the need for more than simple extrapolation and to control for fuel prices, economic activity, and weather events. One simple solution could be to truncate the regression dataset by eliminating data from earlier years; however, such an approach will reduce the degrees of freedom of the model, decrease accuracy, and lose valuable behavior response information gained from weather, fuel price, and economic events. By including these factors, we not only improve the accuracy of our model's forecasts, but also enable policy makers to perform various what if scenarios in their states.

Figure 1: Simple Extrapolation of United States Energy Consumption, 1960-2030

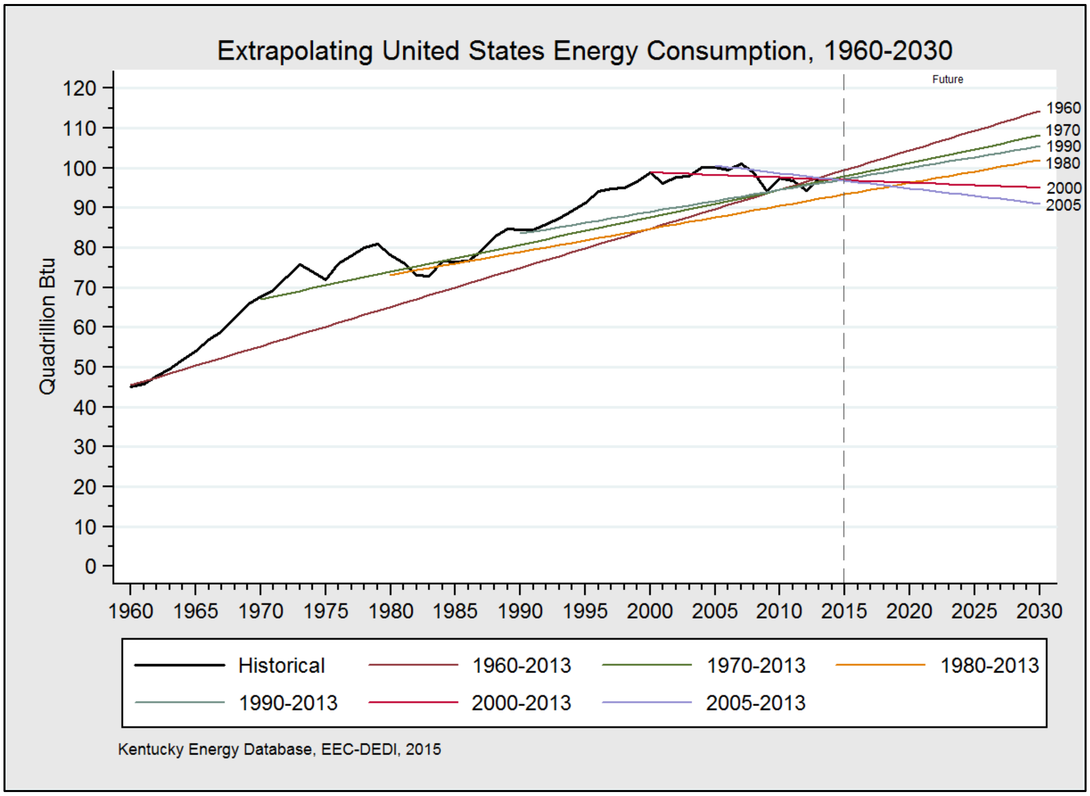
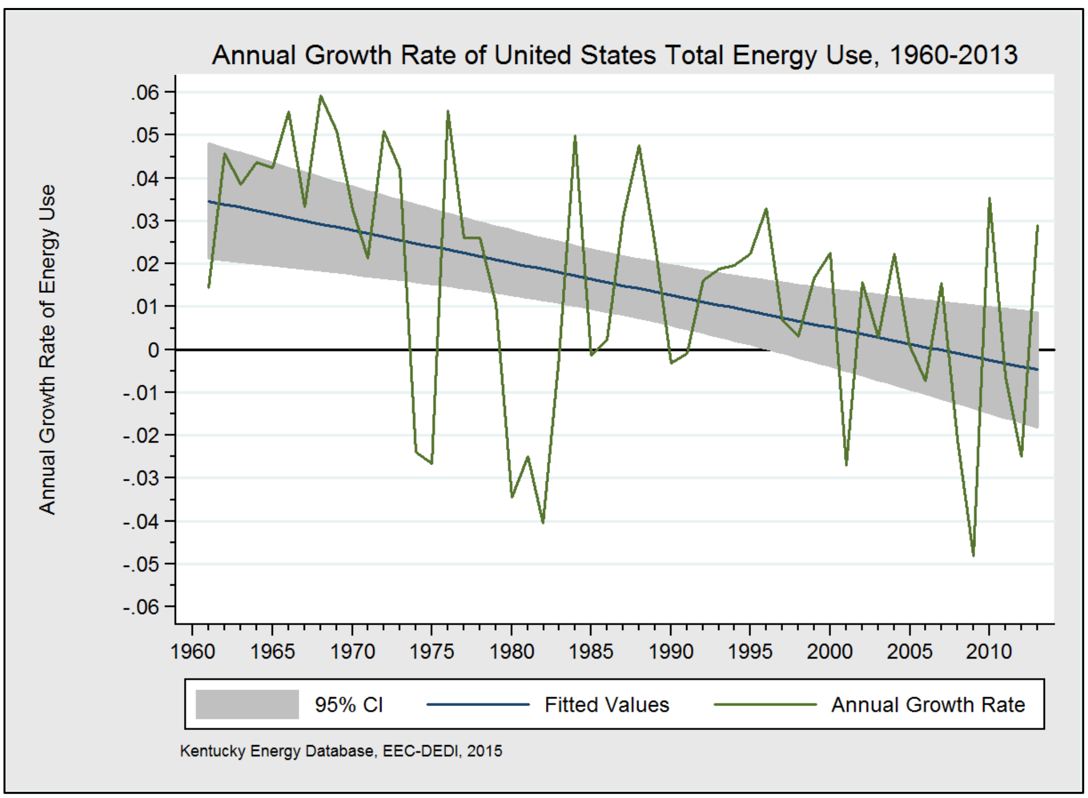
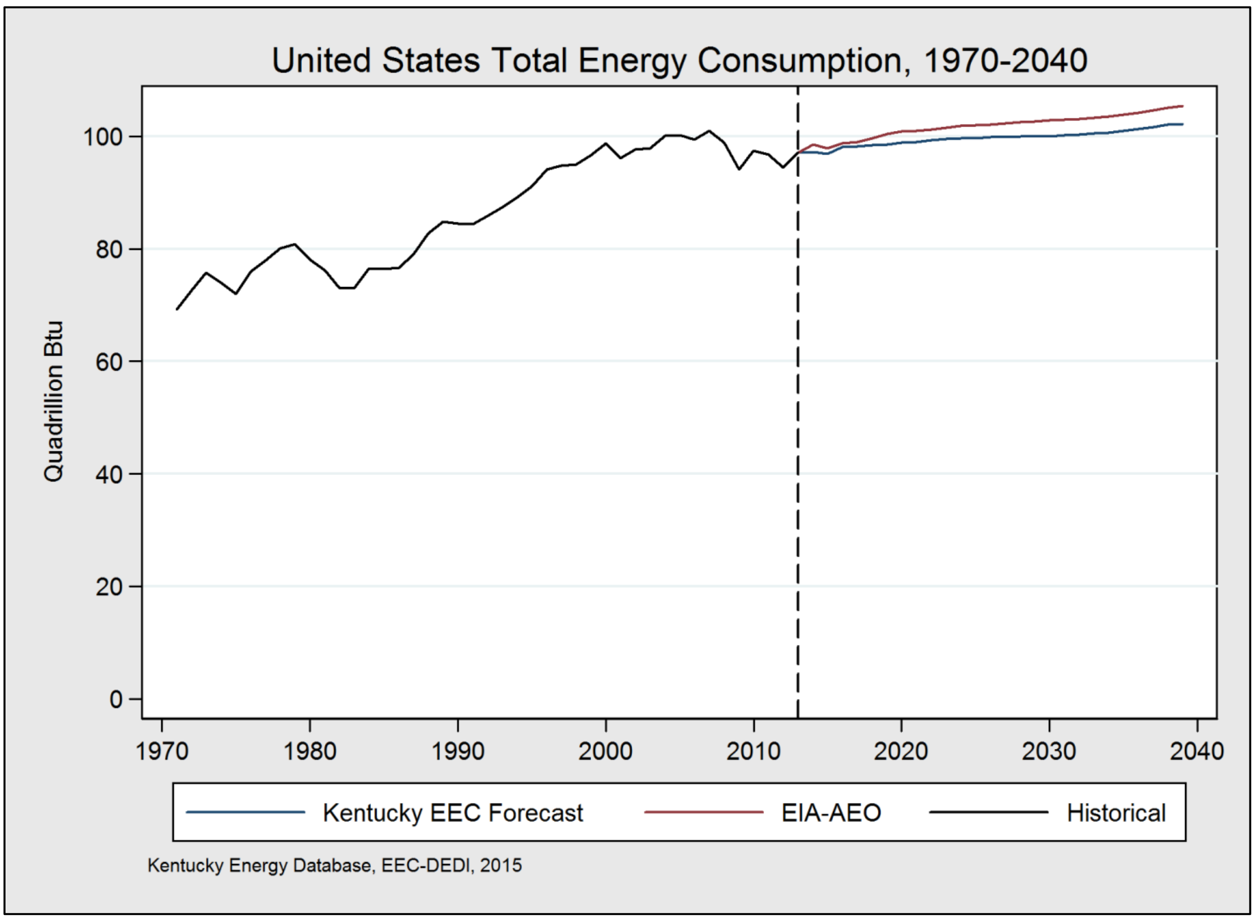


Figure 2: Annual Growth Rate of United States Total Energy Use, 1960-2013



In Figure 3, below, we compare our model's projections to those of the Energy Information Administration (EIA) Annual Energy Outlook (AEO-2015)—the standard upon which most public energy use forecasts are based. While our results are similar, we show a 40% slower rate of growth in total energy consumption compared to the EIA—a 0.314% versus 0.194% constant annual growth rate (CAGR). The EIA forecast for the year 2040 yields 3.3% higher energy use nationally than we project—or 105.73 Quadrillion Btu versus 102.36 Quadrillion Btu. If the EIA is indeed overestimating energy use as our results suggest, then the EIA is likely also overestimating fuel use and carbon dioxide emissions. For state government policy makers—where most energy policy is actually established—our model provides state-level results. State-level energy use forecasts are not provided by the EIA, which leaves many states to extrapolate growth, assume that the EIA's national or regional growth rates apply to their state, or to hire a private consultant.

Figure 3: Forecast Comparison with the Annual Energy Outlook[12]



[2] "Annual Energy Outlook 2015 with Projections to 2040," *EIA,* April 2015, http://www.eia.gov/forecasts/aeo/pdf/0383(2015).pdf

The increasing role of energy efficiency is an important part of the energy consumption discussion. While energy consumption in the United States increased from 45.1 quadrillion British thermal units (Btu) up to 97.1 quadrillion Btu in 2013, during this time period, Americans increasingly received more economic output per unit of energy with the steady decline in energy intensity. The current average energy intensity per capita is nearly half what it was during the early 1970's. Even a multiple regression of numerous independent variables—especially serially autocorrelated variables such as population—risks a similar overestimation energy demand as an extrapolation because the relationship between these independent factors, such as the number of people living in a state, and energy use is changing.

When combined with environmental concerns, business decisions, and government regulations, providing accurate historical data and forecasts becomes even more pertinent for policymakers and businesses. Without accurate forecasts, power companies may overestimate their customer's demand and overbuild generating capacity, policymakers might overestimate a state's capability to adhere to regulations, and an energy intensive factory could potentially be forced to close its doors due to predictable increases in energy prices that make manufacturing cost prohibitive. The consequences of imprecision can be costly. It is, therefore, imperative to increase our understanding of influences to energy demand and provide as accurate of a forecast of future consumption as possible.

In this paper, we will first explore the existing academic literature on modeling energy demand and focus specifically on papers written for each economic sector. Second, we will explain the methodology we used to build upon existing research. Third, we will discuss the specific variables we included in our model and why. Fourth, we will discuss our model's results and potential policy implications before making some final conclusions.

Literature Review

The Oil Crisis of the 1970's spiked interest surrounding energy, as policy makers, academics, and businesses saw the huge impact that high petroleum prices had on the economy. Overnight, energy literature exponentially multiplied as economists sought to explore how we consumed energy, what drove its demand, and what possible relationships it had with other economic factors. Researchers began to study its relationship with Gross Domestic Product (GDP),[3] its impact on

[3] John Kraft and Arthur Kraft, "Relationship between Energy and GNP," *J. Energy Dev.;(United States)* 3, no. 2 (1978).

carbon emissions,[4] and its potential for increased efficiency through government policies such as Energy Star.[5] Alongside this captivation came an interest in energy efficiency. Since the 1970's, the United States' total energy intensity has largely been in decline. Such a decline indicates that energy consumers are gaining more utility per Btu of energy consumed, which has large economic and environmental impacts.

The scale and scope of this econometric research varied widely. These researchers divided energy consumption by fuel source, economic sector, region of interest, and range. For instance, Arsenault et al. focused on the market share of each fuel within each sector in Québec,[6] while Swan and Ugursal looked into end-use consumption solely within the residential sector.[7] The literature surrounding energy consumption is unequally distributed across these divisions. According to Denton et al., the commercial sector is often neglected due its ambiguous makeup and the lack of a unanimous definition.[8] Meanwhile, the residential sector received significantly more attention. By gaining a better grasp of how energy consumption can be forecasted; environmental, financial, and governmental policies can be better supported with accurate data.

The majority of energy demand literature is focused on consumption at the national level. According to Olatubi and Zhang, this largely stems from the lack of easily accessible data at the regional and state level.[9] This blinds policymakers from being able to observe and predict energy and economic impacts of national policies at the regional level. For instance, an energy policy that is benign for service economies like Florida or New York, and perhaps even the majority of the United States, may be harmful to more energy-intensive manufacturing economies like Indiana or Kentucky. Nonetheless, there have been several state and regional studies of energy demand. For instance, Arsenault et al. focused on the market shares of each fuel source, which included oil, natural gas, and electricity, by sector in Québec.[10] Within their model, they utilized the previous year's total energy, price of total energy, price index, real income, heating degree days, and demand

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[4] Ugur Soytas, Ramazan Sari, Bradley T. Ewing, "Energy Consumption and GDP: Causality Relationship in G-7 Countries and Emerging Markets," *Energy economics* 25, no. 1 (2003): 33-37.
[5] Marla C. Sanchez, Richard E. Brown, Carrie Webber, and Gregory K. Homan, "Savings Estimates for the United States Environmental Protection Agency's ENERGY STAR Voluntary Product Labeling Program." *Energy policy* 36, no. 6 (2008): 2098-2108.
[6] E. Arsenault, J-T. Bernard, C. W. Carr, and E. Genest-Laplante, "A Total Energy Demand Model of Québec: Forecasting Properties," *Energy Economics*17, no. 2 (1995): 163-171.
[7] Lukas G. Swan and V. Ismet Ugursal, "Modeling of End-Use Energy Consumption in the Residential Sector: A Review of Modeling Techniques," *Renewable and Sustainable Energy Reviews* 13, no. 8 (2009): 1819-1835.
[8] Frank T. Denton, Dean C. Mountain, and Byron G. Spencer, "Energy Demand with Declining Rate Schedules: an Econometric Model for the US Commercial Sector," *Land Economics* 79, no. 1 (2003): 86-105.
[9] Williams O. Olatubi and Yan Zhang, "A Dynamic Estimation of Total Energy Demand for the Southern States," *The Review of Regional Studies* 33, no. 2 (2003): 206-228.
[10] E. Arsenault, J-T. Bernard, C. W. Carr, and E. Genest-Laplante, "A Total Energy Demand Model of Québec"

of each energy source as their independent variables. Olatubi and Zhang also modeled energy demand within 16 states of the United States.[11] While limited in their access to relevant data, their explanatory variables included energy consumption, heating and cooling degree days, energy price, state population, and an index of the proportion of state total output that comes from manufacturing.[12] Olatubi and Zhang discovered that, while energy consumption will continue to grow as a whole, the South has decreased its energy intensity as it continues to increase efficiency at the industrial level and transition to a more service-based economy.[13] Our model builds upon these state-based studies, by modeling sector-specific state-level energy use.

Residential

The residential sector received a large amount of attention due to the size of its consumption and the multitude of conservation opportunities within it. Since the residential sector is a major contributor to the United States' energy consumption, academics and policymakers have focused on possible ways to reduce consumption. According to Aroonruengsawat et al., efficiency standards, efficiency investment incentives, reduction of government consumption, and information outreach are the four main avenues policymakers utilize to reduce consumption.[14] They focused on the impact of efficiency standards in the residential sector through building codes and discovered that the United States' residential sector consumed 2.09-4.98% less electricity because of these codes.[15] Brounen et al. also looked at how demographics affected residential consumption within 300,000 Dutch homes.[16] They discovered that natural gas consumption was based on the characteristics of the dwelling, such as size, age, and other factors.[17] Meanwhile, electricity consumption was primarily based on household demographics, such as income, family composition, age, and characteristics.[18] While accounting for the impact that housing structure, ideology, and residential demographics have on electricity consumption, Costa and Kahn discovered that California's flat consumption in the residential sector was caused by an increase in newer energy efficient homes due to updated building

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[11] Williams O. Olatubi and Yan Zhang, "A Dynamic Estimation of Total Energy Demand for the Southern States"
[12] Ibid
[13] Ibid
[14] Anin Aroonruengsawat, Maximilian Auffhammer, and Alan H. Sanstad, "The Impact of State Level Building Codes on Residential Electricity Consumption," *Energy Journal-Cleveland* 33, no. 1 (2012): 31.
[15] Ibid
[16] Dirk Brounen, Nils Kok, and John M. Quigley, "Residential Energy Use and Conservation: Economics and Demographics," *European Economic Review* 56, no. 5 (2012): 931-945.
[17] Ibid
[18] Ibid

codes.[19] They predicted that the sector's stagnant growth in consumption will eventually decrease as the older, inefficient buildings with building codes that did not account for energy efficiency are replaced with newer, efficient buildings with updated building codes.[20]

Transportation

Transportation is one of the most visible energy sectors within the United States. While the majority of people might not know how much they pay to keep their computer on, they can easily recite how much they paid for their commute to work this week. In part, this is due to the lack of any major, widespread substitute for petroleum use and the general necessity of motorized transportation for many Americans. Simplified, energy consumed within transportation is found by dividing the distance a population traveled within a year by the fuel efficiency of the population's transport fleet.[21] However, many modelers lack these fundamental variables due to their difficulty in accurately predicting them or the lack of such data. They utilize other variables to help explain consumption within the transport sector. For instance, Parbhakar found that disposable income plays a major role in car utilization in his Québec model.[22] Eltony also utilized the unemployment rate within his model to explain gasoline consumption in Canada.[23] He discovered that improving fuel efficiency is an effective way to minimize household gasoline consumption.[24]

Efficiency plays a huge role when examining the transportation sector. It can encourage car owners to drive more since their transportation costs are lower. One of the main ways policymakers increase fuel efficiency is through miles per gallons (mpg) standards. It helps maintain a standard level of efficiency by inhibiting people from buying inefficient cars during periods of low gas prices. When the prices rise, people lean towards purchasing efficient vehicles. It can also be difficult to increase efficiency outside of fuel standards, due to people not driving at their car's optimal fuel efficiency speeds. For instance, the 70 mph speed limit in the United Kingdom is exceeded by 57% of drivers, while the optimum speed for fuel economy in most cars is between 55-60 mph.[25] Unless

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[19] Dora L. Costa and Matthew E. Kahn, "Why Has California's Residential Electricity Consumption Been So Flat since the 1980s?: A Microeconometric Approach," *UCLA* (2010).
[20] Ibid
[21] George Kouris, "Fuel Consumption for Road Transport in the USA," *Energy Economics* 5, no. 2 (1983): 89-99.
[22] K. J. Parbhakar "Fuel Consumption for Road Transport in Québec." *Energy economics* 8, no. 3 (1986): 165-170.
[23] M. Nagy Eltony, "Transport Gasoline Demand in Canada," *Journal of Transport Economics and Policy* (1993): 193-208.
[24] Ibid
[25] David Bonilla and Timothy Foxon, "Demand for New Car Fuel Economy in the UK, 1970-2005," *Journal of Transport Economics and Policy* (2009): 55-83.

the government lowers the speed limit and creates a successful public relations campaign that admonishes speeding, it is unlikely that this inefficiency will be fixed.

Commercial

While the commercial sector can be difficult to estimate in some countries and regions due to its ambiguous sectoral boundaries and building classifications, it greatly impacts a region's total energy consumption.[26] Lighting, climate control, appliances, and equipment all heavily contribute to the commercial sector's consumption. For instance, data centers alone were responsible for nearly 1.3% of total global electricity use in 2010 and doubled between 2000 and 2005, while slowing down in growth during 2005 to 2010.[27] Otsuka sought to expand the literature of electricity demand within the industrial and commercial sectors at the prefecture level due to the limited research of Japan at the sectoral level, the need for determining the effect price hikes will have on demand, the commercial and industrial dominance of 70% of the total energy portfolio in Japan, and the changing composition of electricity generation due to the suspension of nuclear facilities.[28] He utilized price factor data, which consisted of the aggregate unit price of electricity and the domestic corporate goods price index; the production factor, which included the amount of real production; cooling degree days; heating degree days; and a lagged demand term as the variables for his fixed effects model of electricity demand.[29] He discovered that the price elasticity within the two sectors in the short and long term is lower than the production elasticity.[30]

The sector is also ripe for efficiency increases. Zhou and Lin used an end-use energy model to evaluate various scenarios of how efficiency improvements, GDP and energy elasticity affected the energy consumption of commercial buildings in China.[31] They discovered that current Chinese statistics underestimated consumption by nearly 44%, current energy efficiency improvements were unable to offset a huge increase in energy intensity within this sector, and that differing amounts of GDP growth and elasticities outcomes could potentially allow for a wide range of floor-area growth

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26 Frank T. Denton, Dean C. Mountain, and Byron G. Spencer, "Energy Demand with Declining Rate Schedules,"

27 Jonathan Koomey, "Growth in Data Center Electricity Use 2005 to 2010," *A Report by Analytical Press, Completed at the Request of The New York Times*(2011): 9.

28 Akihiro Otsuka, "Demand for Industrial and Commercial Electricity: Evidence from Japan," *Journal of Economic Structures* 4, no. 1 (2015): 9.

29 Ibid

30 Ibid

31 Nan Zhou and Jiang Lin, "The Reality and Future Scenarios of Commercial Building Energy Consumption in China," *Energy and Buildings* 40, no. 12 (2008): 2121-2127.

scenarios, which would increase consumption.[32] Sharma et al. also studied commercial energy consumption in the Indian state of Kerala.[33] Due to government subsidies that perpetuated inefficiencies, Sharma et al. discovered that electricity demand within all sectors of Kerala was not sensitive to the state's subsidized prices.[34] They also discovered that energy consumption within the state is sensitive to changes in the state's state domestic product.[35] Sharma et al. proposed that efficiency within the region could be increased if the state-owned utility priced energy at its real cost, which would allow it to focus on investing capital-intensive additions and pressure consumers to make efficient choices.[36]

Industrial

Depending on the economy's composition, the industrial sector can be one of the most energy-intensive sectors. The variance in energy demand within the industrial sector is substantial as building construction is less energy intensive than steel or aluminum.[37] According to Berndt and Wood, industrial energy demand is a derived demand that stems from it being considered a production input.[38] They also conclude that investment tax credits will lower the cost of capital and energy, which would encourage energy consumption.[39] This has important implications for policymakers, as they need to target energy-efficient economic incentives if they want to encourage economic activity while limiting increased energy consumption. Meanwhile, Eltony created an industrial energy model and forecast for Kuwait in order to help policymakers make informed decisions, which might include lowering or canceling Kuwait's high oil subsidy at the time.[40] He divided the Kuwait industrial sector by subsectors, such as petrochemical production, desalination, and non-oil industries; and then created a baseline, moderate, and extreme version of his predictions.[41] His research reveals that energy consumption will continue to grow in the foreseeable future, that Kuwait's electricity prices should be adjusted immediately following a change in fuel

[32] Ibid
[33] D. Parameswara Sharma, PS. Chandramohanan Nair, and R. Balasubramanian, "Demand for Commercial Energy in the State of Kerala, India: An Econometric Analysis with Medium-Range Projections," *Energy policy* 30, no. 9 (2002): 781-791.
[34] Ibid
[35] Ibid
[36] Ibid
[37] François Lescaroux, "Industrial Energy Demand: A Forecasting Model Based on an Index Decomposition of Structural and Efficiency Effects," *OPEC Energy Review* 37, no. 4 (2013): 477-502.
[38] Ernst R. Berndt and David O. Wood, "Technology, Prices, and the Derived Demand for Energy," *The Review of Economics and Statistics* (1975): 259-268.
[39] Ibid
[40] M. Nagy Eltony, "Industrial Energy Policy: A Case Study of Demand in Kuwait," *OPEC Review* 30, no. 2 (2006): 85-103.
[41] Ibid

prices in order to discourage massive inter-fuel substitutions within the economy, and that a sharp increase in energy prices may have an adverse effect on the economy while only slowly reducing consumption rates.[42] In addition, Dilaver and Hunt predicted future Turkish industrial consumption by utilizing industrial value added, electricity prices, and electricity consumption from 1960-2008 data.[43] They sought to create a forecast that did not overestimate Turkish energy consumption and could help guide policymakers in establishing efficiency standards in order to meet Turkey's Kyoto requirements, sustain its energy security goals, and maintain its export-oriented economic policy.[44]

Methodology

Researchers have utilized several different techniques to predict consumption, such as fuzzy-logic, fixed effects regression, ordinary least squares, decision trees, mixed fixed random coefficients, two-way effects, artificial neural networks, and evolutionary algorithms. We have built upon their research by developing 4 simultaneous equations using multiple regression of panel data with fixed effects. Prior to analysis, we converted all variables to their natural logarithms so their coefficients may be interpreted as elasticities. All coefficients are homogenous across space and time with only the data and fixed effects changing between states.

The multiple regression of panel data with fixed effects model can be generally given by,

$$Y_{it} = \beta_0 + \sum_{j=1}^{k-1} \beta_j X_{jit} + \alpha_i + \varepsilon_{it}$$

Where i and t index states and years, such that Y_{it} is the dependent variable of interest, energy consumption, in state *i* in year *t*, β_0 is the constant *y* intercept across all states, X is a *k* by 1 vector of explanatory variables, $\beta_j X_{jit}$ is the product of the observation for each independent variable *j* through k for state *i* in year *t* and the coefficient of X, *k* is the total number of included independent variables, a_i is the time-invariant fixed effect for state *i*, and ε_{it} are the residuals, and where $\varepsilon_{it} \sim N(0, \sigma 2)$, or are approximately normally distributed with a mean of zero.

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[42] Ibid

[43] Zafer Dilaver and Lester C. Hunt, "Industrial Electricity Demand for Turkey: A Structural Time Series Analysis," *Energy Economics* 33, no. 3 (2011): 426-436.

[44] Ibid

Table 1: Coefficients and Standard Errors in Sectoral Energy Consumption Models

	Commercial	Industrial	Residential	Transportation
Population	0.344***	0.166***	0.919***	
	(22.66)	(6.03)	(72.64)	
Drivers Licenses				0.262***
				(15.88)
Sectoral Electricity Consumption	0.701***	0.697***		
	(61.27)	(53.18)		
Real Sectoral Electricity Rate	-0.078***		-0.161***	
	(-6.49)		(-13.86)	
Real Sectoral Natural Gas Price	0.0207*	0.0751***	0.323***	
	(2.03)	(4.46)	(24.58)	
Percentage of Natural Gas and Total Sectoral Consumption	0.581***	0.610***	0.842***	
	(11.59)	(7.78)	(14.90)	
Natural Gas Interaction Term	-0.0575***	-0.0551***	-0.336***	
	(-7.64)	(-4.41)	(-28.42)	
Real Sectoral Gasoline Price				0.604***
				(8.82)
Percentage of Motor Gasoline and Total Sectoral Consumption				-0.258***
				(-2.22)
Motor Gasoline Interaction Term				-0.709***
				(-10.37)
Real Sectoral Petroleum Price		-0.172***		
		(-11.66)		
Real per Capita Personal Income	0.279***		0.244***	
	(9.30)		(9.23)	
Real Total Personal Income				0.550***
				(33.75)
Weather (Heating and Cooling Degree Days)	0.259***	0.141**		
	(9.34)	(2.67)		
Cooling Degree Days			0.0298***	
			(3.74)	
Heating Degree Days			0.327***	
			(18.79)	
Year	-18.95***			-3.260***
	(-18.65)			(-3.68)
Year pre-2000		-21.15***	-3.663***	
		(-16.84)	(-3.73)	
Year post-2000		14.693***	-8.413***	
		(5.78)	(-8.04)	
Real GDP from Farms		0.0792***		
		(6.69)		
United States Car Fleet Average Miles per Gallon				-0.581***
				(-20.61)
Constant	139.2***	51.12**	84.56***	25.16***
	(18.78)	(2.96)	(6.55)	(3.83)
R2 Within	0.951	0.673	0.909	0.942
R2 Between	0.997	0.907	0.956	0.975
R2 Overall	0.993	0.897	0.954	0.973
N	2112	2112	2112	2112

*Asterisks denote statistical significance at the following levels: * p<0.05, ** p<0.01, *** p<0.001.*
Standard errors are shown in parentheses.

Table 2: Variables Utilized in the Energy Consumption Models

Variable	Unit of Measure	Source
Electricity Price	Dollars per Kilowatt	Energy Information Administration's State Energy Data System
Price of Natural Gas	Dollars per MMBtu	Energy Information Administration's State Energy Data System
Price of Motor Gasoline	Dollars per MMBtu	Energy Information Administration's State Energy Data System
Price of Petroleum	Dollars per MMBtu	Energy Information Administration's State Energy Data System
Driver's Licenses	Driver's Licenses issued in each state	Department of Transportation's Research and Innovative Technology Administration
Fuel Efficiency	Average miles per gallon of the United States car fleet	Energy Information Administration
Personal Income	Personal Income or Per Capita Personal Income	Bureau of Economic Analysis
Electricity Demand	Gigawatt Hours	Energy Information Administration's State Energy Data System and EIA 826
Weather	Heating Degree, Cooling Degree, and Total Degree Days	National Oceanic and Atmospheric Administration
Agricultural Production	GDP from the Animal and Crop Production Industries	Bureau of Labor Statistics
Natural Gas and Motor Gasoline percentages	Fuel used divided by total sectoral energy consumption	Energy Information Administration’s Data State Energy Data System
Natural Gas and Motor Gasoline Interaction Terms	Percentage of Fuel and total sectoral energy multiplied by the real price of the fuel	Energy Information Administration’s Data State Energy Data System
Population	Population in each state	United States Census
Year	The Year, Years before 2000, and Years after 2000	

Variable Selection

We utilize a variety of experimental variables in each sector-specific model. While a good portion of our independent variables are repeated across sectors, there are a few key exceptions. Within the commercial, industrial, and residential sectors, we included electricity consumption or electricity prices along with natural gas prices in order to take into account price elasticity of demand. Both of these sources are significant providers of energy within these economic sectors and are often substituted for each other. We analyze them separately to understand what substitution effects may occur between the two fuels. By including prices, we hoped to incorporate their elasticity of demand. Combined with the inclusion of interactive terms that included the percentage of fuel used within a sector and the multiplication of this percentage with real fuel prices, we hoped to measure the effect motor gasoline and natural gas prices and quantities had within certain sectors.

Population, and by extension driver's licenses in the transportation sector, are utilized within each sector to help illustrate population's positive relationship with energy consumption. Provided that the rate of consumption per capita remains unchanged, more energy will be consumed as long as the population continues to increase.[45] In addition to these price variables, we included personal income or per capita personal income within these sectors. Income's relationship with energy consumption has been extensively studied, with multiple differing conclusions being made about its causality.[46] By including income, we can see how it creates or reflects energy consumption in our panel database.

For commercial, industrial, and residential buildings, weather can have a significant impact on a building's energy consumption. In order to maintain a comfortable environment, building users will utilize energy-intensive air conditioning/heating units. As demonstrated by Giannakopoulos and Psiloglou, energy consumption has a non-linear, U-shaped relationship with temperature.[47] As the temperature begins to rise or drop after a certain point, energy consumption increases. Depending on the sector, degree days are frequently used as a variable to help estimate energy and electricity demand, as seen in Otsuka's,[48] Holtedahl and Joutz's,[49] and Denton et al.'s work.[50] We measure this

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[45]Allan Mazur, "How Does Population Growth Contribute to Rising Energy Consumption in America?," *Population and Environment* 15, no. 5 (1994): 371-378.

[46] Ugur Soytas, Ramazan Sari, and Bradley T. Ewing, "Energy Consumption and GDP: Causality Relationship in G-7 Countries and Emerging Markets,"

[47] Christos Giannakopoulos and Basil E. Psiloglou, "Trends in Energy Load Demand for Athens, Greece: Weather and Non-Weather Related Factors," *Climate Research* 31, no. 1 (2006): 97.

[48] Akihiro Otsuka, "Demand for Industrial and Commercial Electricity"

[49] Pernille Holtedahl and Frederick L. Joutz, "Residential Electricity Demand in Taiwan," *Energy Economics* 26, no. 2 (2004): 201-224.

by using National Oceanic and Atmospheric Administration (NOAA) data, which sets the base temperature at 65˚degrees.[51] Depending on the sector, we either combine them into one degree day variable (weather) in order to track the total deviation from the base temperature or separate them into heating and cooling degree day variables.

In theory, consumption within the transportation sector would be as easy as calculating the total distance traveled that year and the combined fuel efficiency of the fleet.[52] However, behavioral influences, such as personal income and the price of traveling, play a significant role in influencing the nature of American drivers.[53] Since the demographic variables change amongst different studies,[54] we have decided to utilize the number of driver's licenses issued and personal income as measures of the driving population and their behavior. Our model also tracks efficiency trends by including the annual average miles per gallon within the United States' car fleet. It should be noted that an increase in fuel efficiency usually encourages more driving, however, this trend has been decreasing recently.[55] In addition to these variables, we include the price of motor gasoline to reveal how consumers change their consumption habits when the price is increased or decreased.

Finally, we have included the United States' farming GDP as way to help track agriculture's impact within the industrial sector. It is able to track energy intensive trends within this particular subsector, such as corn drying and ethanol production. Due to corn's tendency to generate fungi quickly after harvest due to its moisture content, farmer's must utilize a variety of preservation and energy intensive drying techniques in order to maintain high crop yields.[56] According to Wang et al., the production of ethanol, which is largely produced from corn, increased from 175 million gallons in 1980 to 4.9 billion gallons by 2006.[57] According to Energy Information Administration's State Energy Data System, the Btu cost of producing fuel ethanol is subtracted from fuel's heat content in order to avoid double counting.[58] The energy losses are then attributed to the states that produce

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50 Frank T. Denton, Dean C. Mountain, and Byron G. Spencer, "Energy Demand with Declining Rate Schedules"
51 "Climate Degree Days." *NOAA.* Last modified January 24th, 2005. http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/cdus/degree_days/ddayexp.shtml
52 George Kouris, "Fuel Consumption for Road Transport in the USA"
53 M. Nagy Eltony, "Transport Gasoline Demand in Canada"
54 Ibid
55 Kenneth A. Small and Kurt Van Dender "The Effect of Improved Fuel Economy on Vehicle Miles Traveled: Estimating the Rebound Effect Using US State Data, 1966-2001," *UC Energy Institute* (2005). http://repositories.cdlib.org/ucei/policy/EPE-014
56 Carl J. Bern,"Preserving the Iowa Corn Crop: Energy Use and CO2 Release,"*Applied Engineering in Agriculture* 14, no. 3 (1998): 293.
57 Michael Wang, May Wu, and Hong Huo, "Life-Cycle Energy and Greenhouse Gas Emission Impacts of Different Corn Ethanol Plant Types," *Environmental Research Letters* 2, no. 2 (2007): 024001.
58 "SEDS Technical Notes & Documentation- Complete 2013: Section 5. Renewable Energy," *EIA,* Last Modified July 24th, 2015, http://www.eia.gov/state/seds/sep_use/notes/use_renew.pdf

fuel ethanol and are counted within their industrial and total energy consumptions.[59] By including farming GDP, we will be able to see the increased demand for corn and, by extension, an increase in energy demanded by companies that grow corn or use it in energy intensive products.

Results

As seen in Figure 3 on page 6, our model yields comparable results to the Energy Information Administration's Annual Energy Outlook for 2015.[60] However, our forecast maintains more moderate growth, while the Annual Energy Outlook predicts that consumption will grow at a 40% higher and faster rate.[61]

In general, our coefficients match the literature surrounding energy consumption. As seen in Figure 2, population, per capita personal income, total personal income, agricultural output, cooling degree days, heating degree days, weather, and driver's licenses have a positive relationship with energy consumption. Fuel and power prices are negatively related to energy consumption. We found that natural gas and motor gasoline interactive terms are better at explaining energy demand than the fuel price or quantity alone. The combination of the percentage of a specific fuel source within a sector and the multiplication of this percentage with real fuel prices lead to better results and maintained the same relationship with energy consumption. In addition, all variables were found to be significant.

When we compared our total consumption model predictions against historical observations from 1970 – 2013, our energy consumption model has an absolute mean error of ± 4%. As seen in Figure 15, it is able to predict energy consumption within ± 1% better than 18% of the time, within ± 10% better than 93% of the time, and within ± 20% better than 99% of the time. Our best performing sector, which was the transportation sector, has an absolute mean error of ± 4%. It is able to predict energy consumption within ± 1% better than 19% of the time and is within ± 10% better than 97% of the time. Our worst performing sector was the industrial sector, which has an absolute mean error of ± 9%. The sector is able to predict energy consumption within ± 1% better than 8% of the time and within ± 10% better than 68% of the time.

It is important to note the model's limitation and its intended use. Due to its relative openness, our model's inputs can easily be adjusted to create forecasts for high or low fuel prices,

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[59] Ibid

[60] "Annual Energy Outlook 2015 with Projections to 2040," *EIA,* April 2015, http://www.eia.gov/forecasts/aeo/pdf/0383(2015).pdf

[61] Ibid

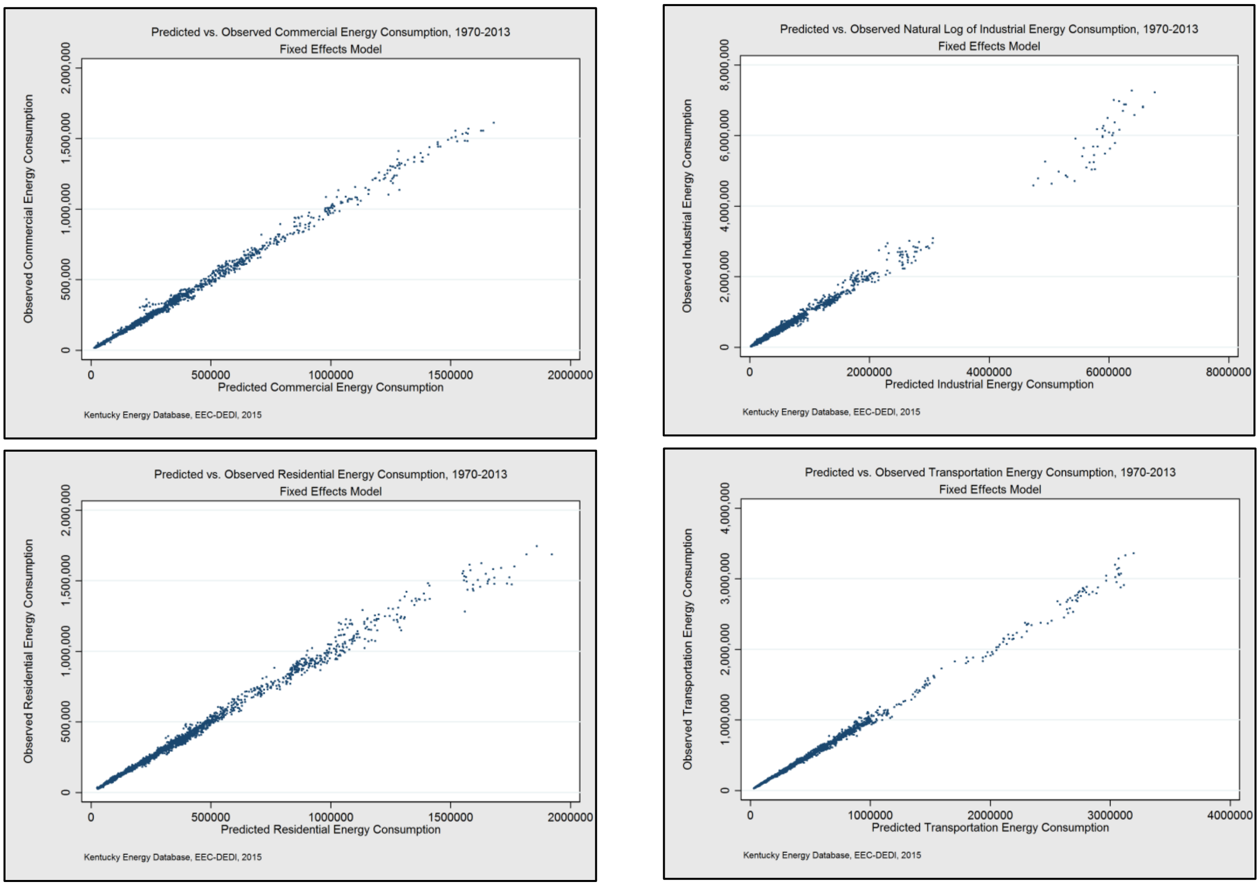
high or low population growth, and any other combination of input changes. While increases or declines in energy consumption within a specific sector may reflect economic growth or decline, it does not prove it. Efficiency improvements, the transformation of a state's economy to less energy intense industries, and other factors can all affect the energy demand of a state without drastically impacting the economy. Furthermore, the end-user should realize that the model is only able to forecast under the assumption of business as usual. Numerous future events, including the decreased substitution of two fuel sources that were previously easily substitutable, drastic changes in fuel prices, technology innovations, unexpected geo-political events, drastic efficiency improvements, and other unknowns can drastically change our model's coefficients or the sectoral energy demand, which would substantially change our forecasts. Most of these events are unpredictable and are not included within our forecast. However, our model is still able to accurately predict historical demand.

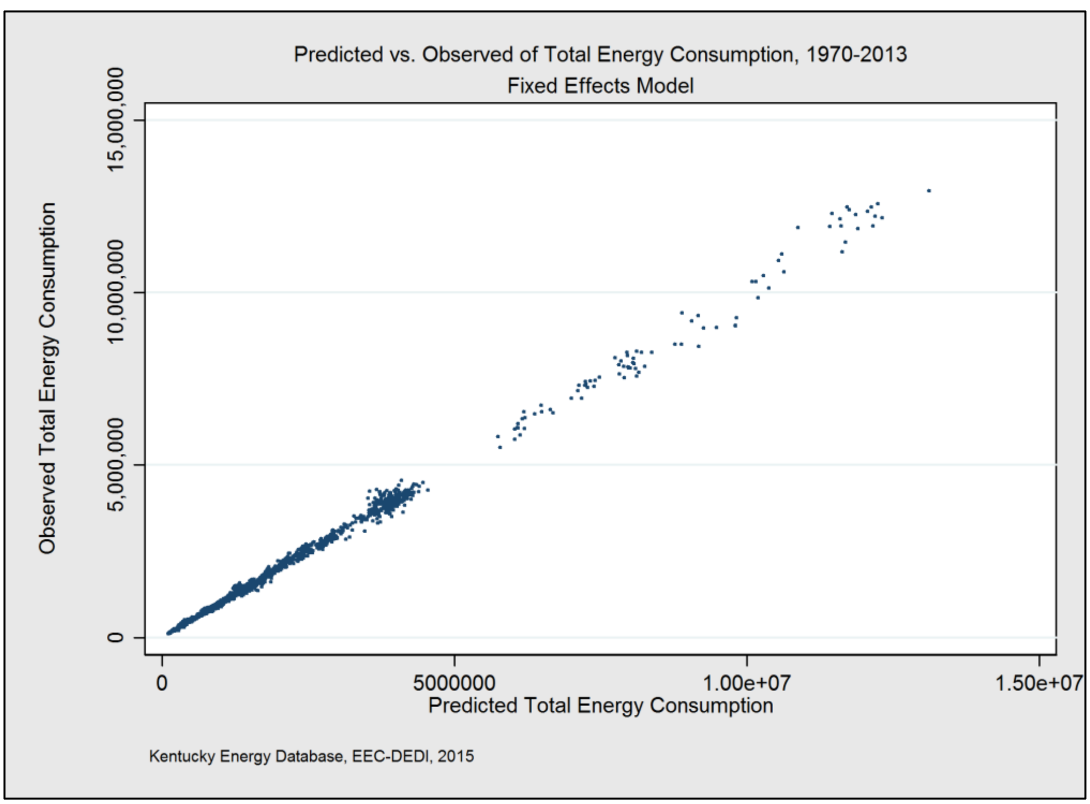
Nonetheless, certain sectors will provide more accurate results than others will. As displayed in Figure 11, plotting residuals over time reveals that our transportation and residential sectors provided more accurate results than the industrial. This is due to the strong effects of motor gasoline and personal income within the transportation model. For the residential sector, this is largely due to population's strong influence. The industrial sector is difficult to predict due to drastically different energy requirements for manufacturing certain goods and population's minimal impact on the sector in comparison to these large energy users. For example, the creation of one aluminum smelter can easily dwarf the consumption of hundreds of homes and dwarf other less energy-intensive processes within the industrial sector itself.

Conclusion

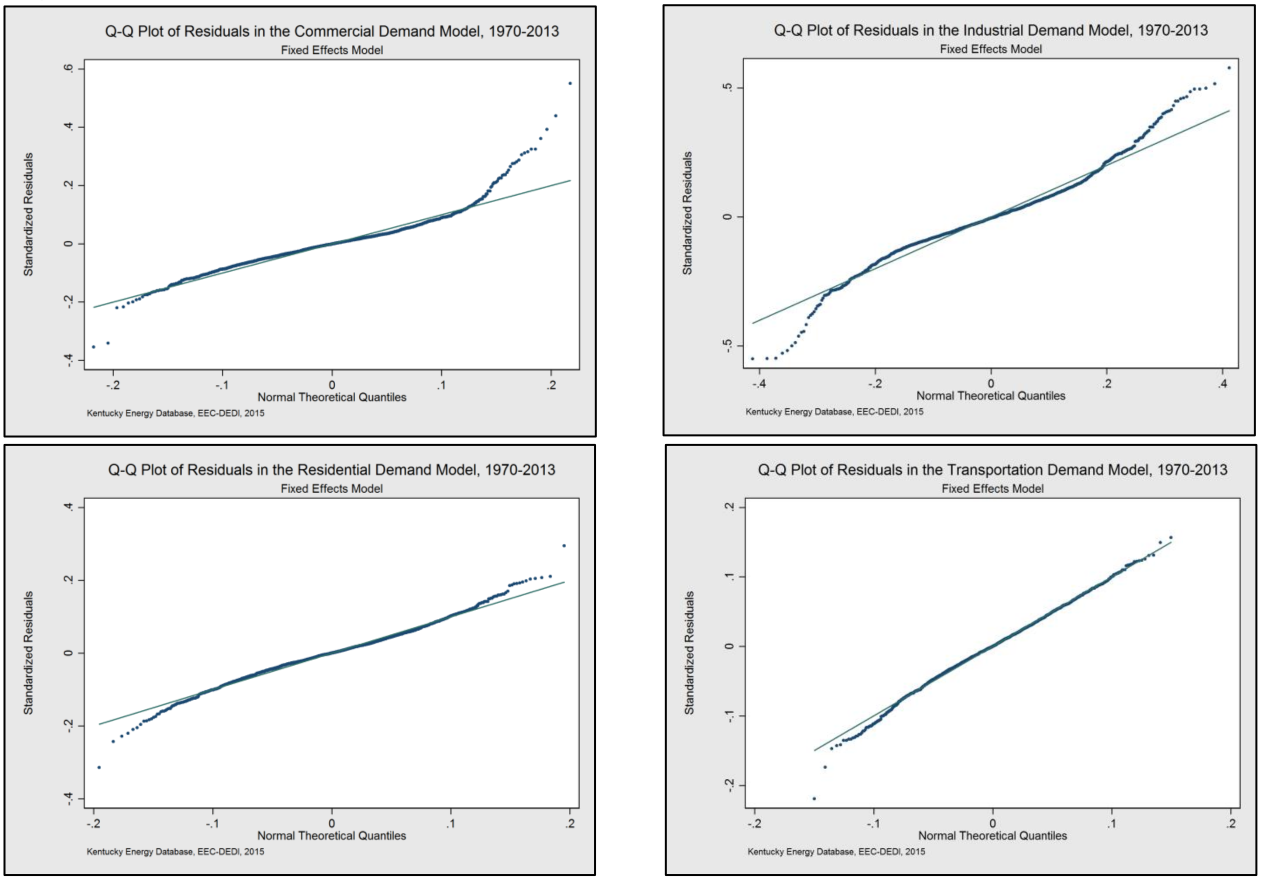
Our analysis of historical energy use data quantifies the degree to which energy consumption is influenced by population, personal income, fuel prices, weather, and the efficiency of energy use. Improvements in energy efficiency already underway indicate that future energy demand will not grow as aggressively as it has in the past. The model presented in this paper is a first-step in helping state government officials to develop state-specific energy consumption forecasts that respond to these variable factors, which are significantly more accurate than simpler extrapolation techniques. Future research should leverage more granular data of the intrastate differences in energy use to further refine model coefficients and parameters since independent factors such as socioeconomics and climate also vary substantially even within states.

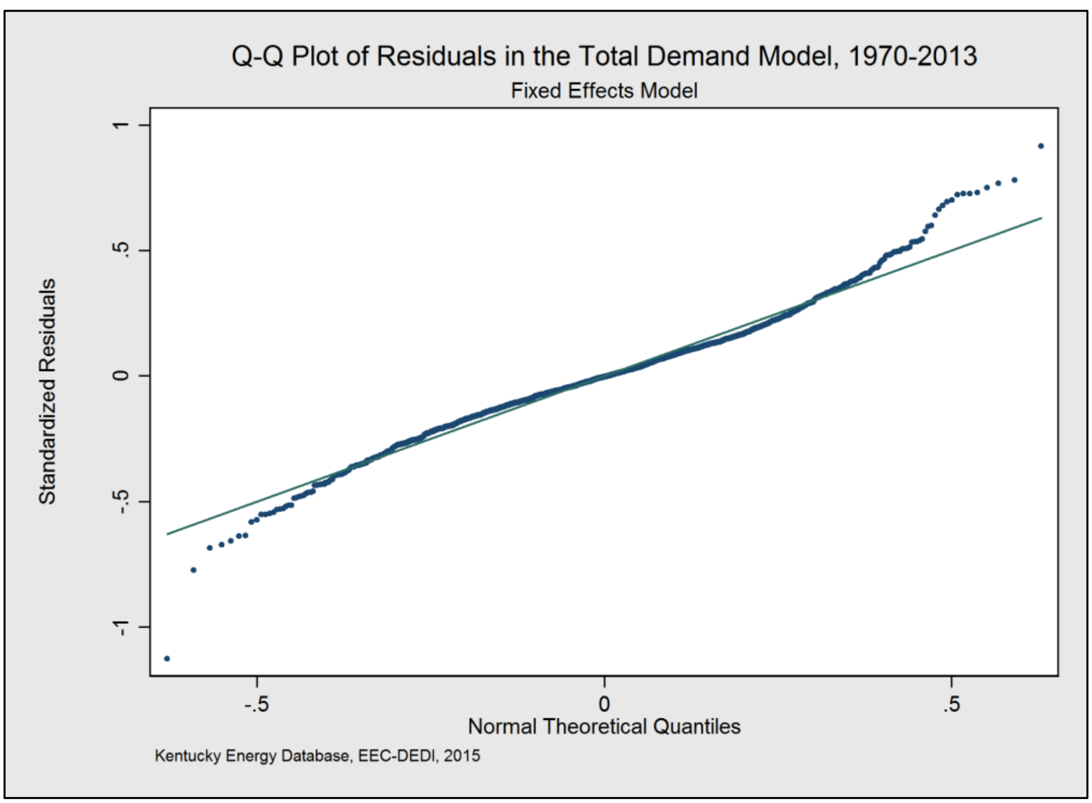
Figures 4 and 5: Sectoral and Total Predicted vs. Observed Plots



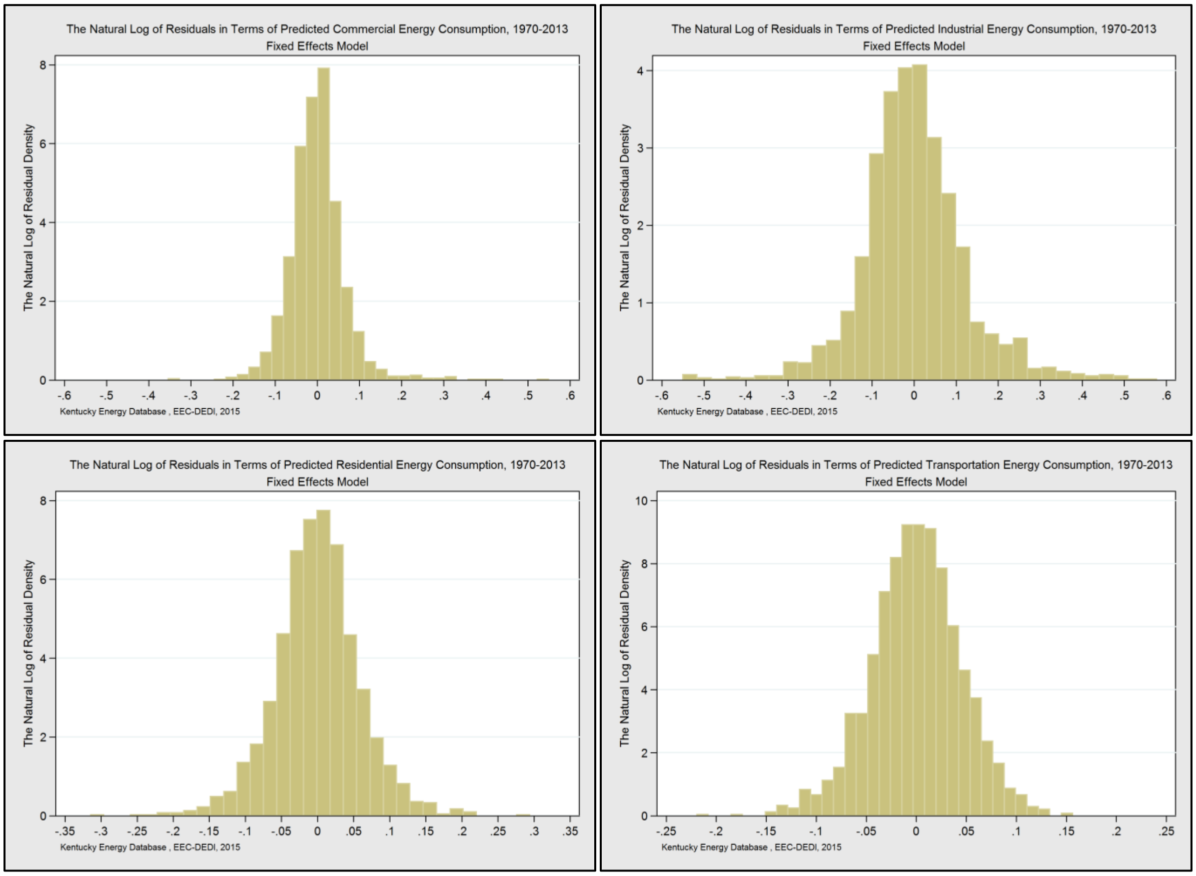


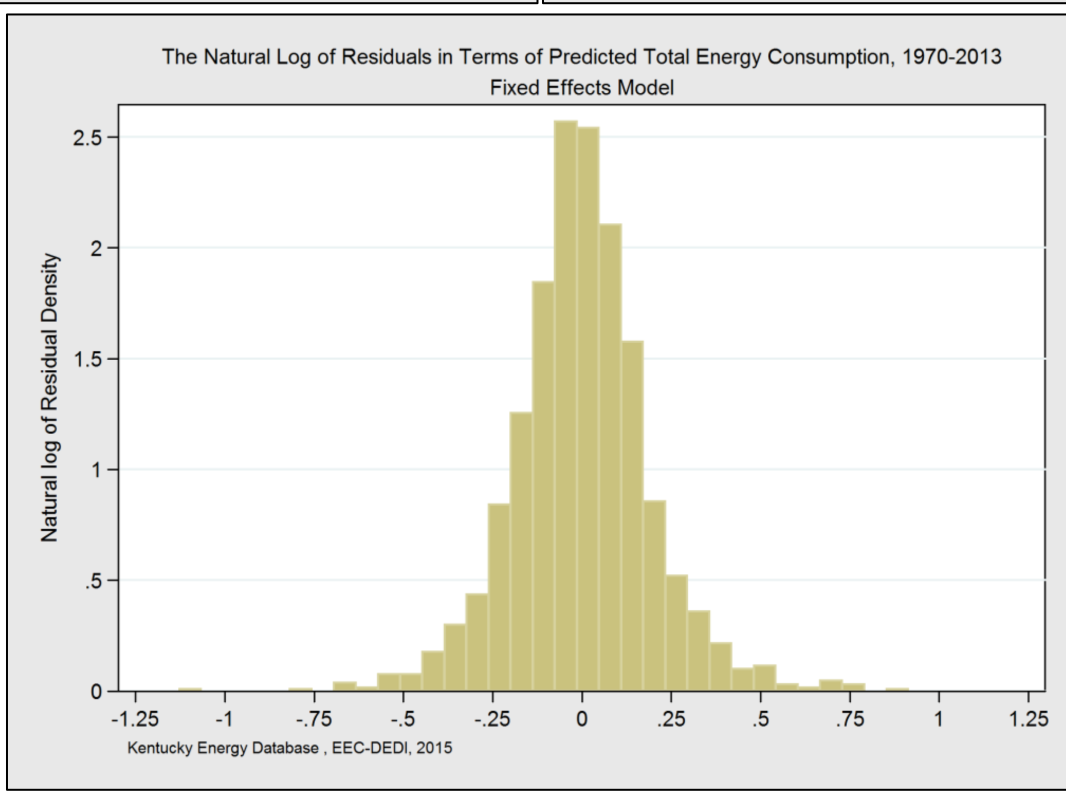
Figures 6 and 7: Sectoral and Total Q-Q Plots





Figures 8 and 9: Sectoral and Total Histogram Plots





Figures 10 and 11: Sectoral and Total Residuals vs. Year Plots

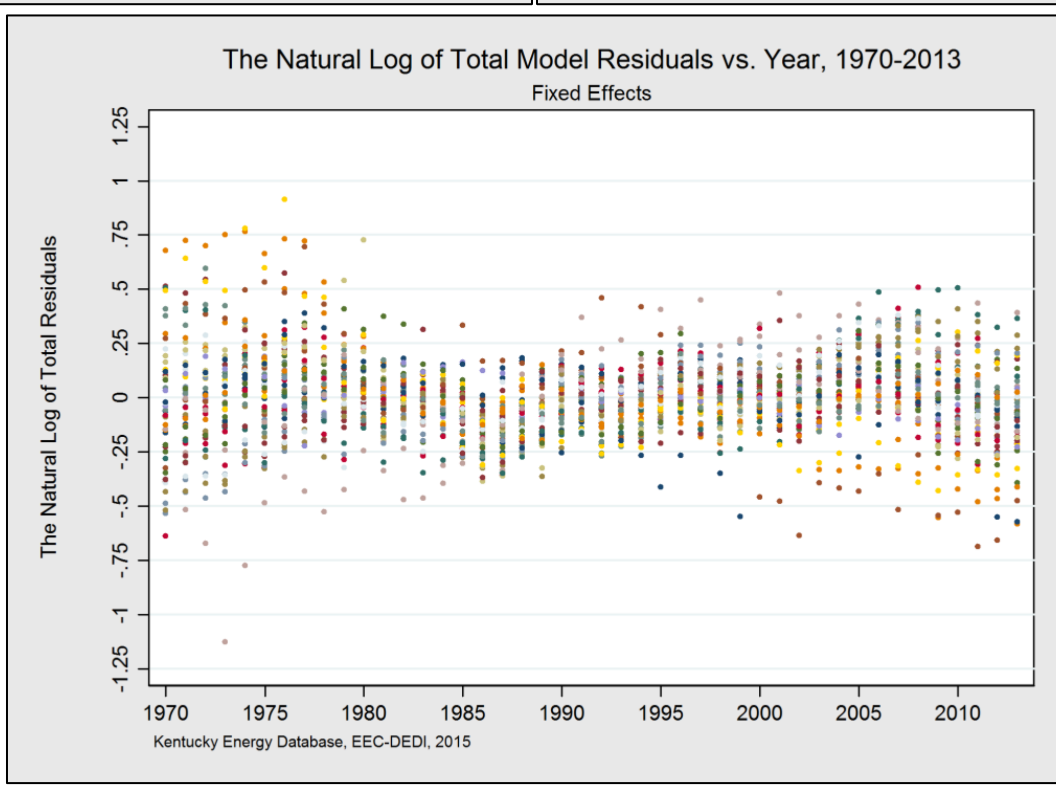


Figure 12: Kentucky Validation Plot

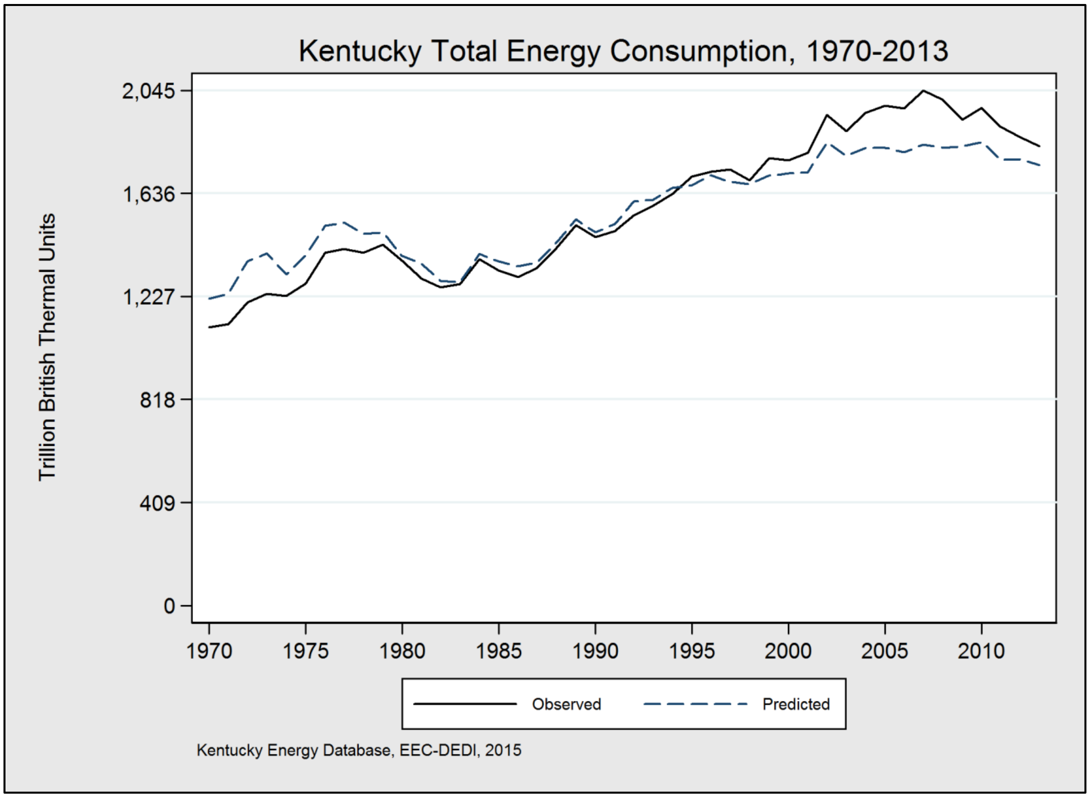


Figure 13: Kentucky Sectoral Forecast

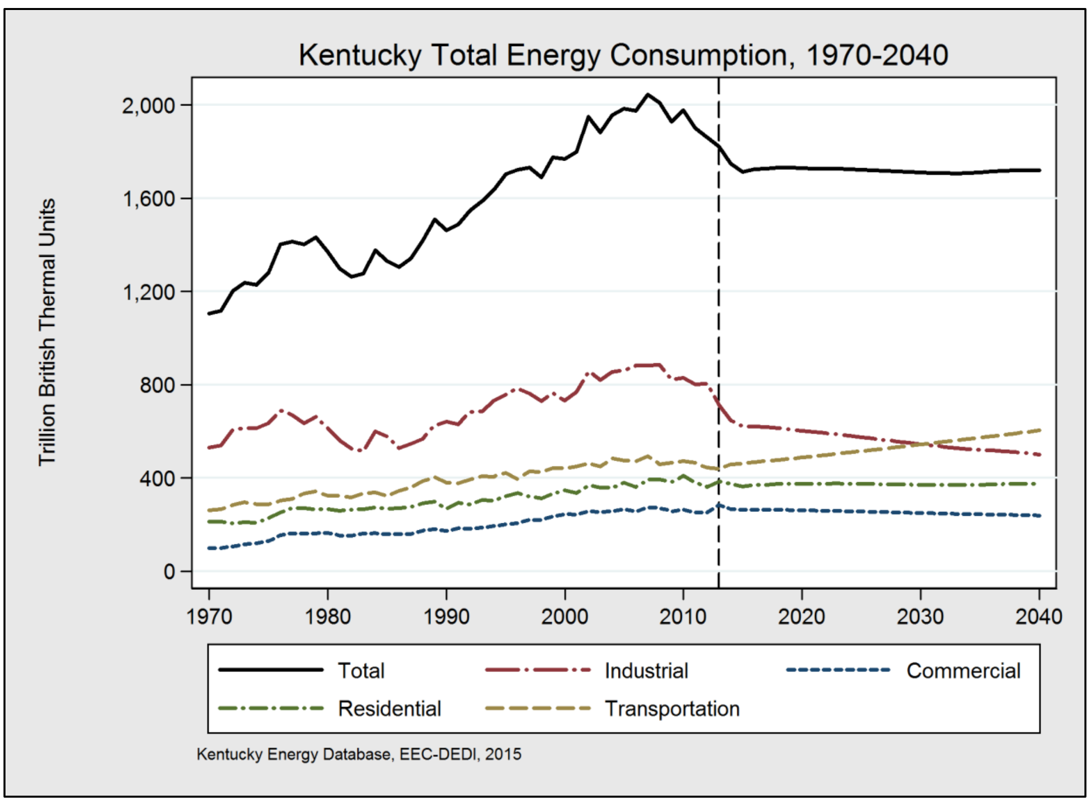


Figure 14: State Validation and Forecast Graphs

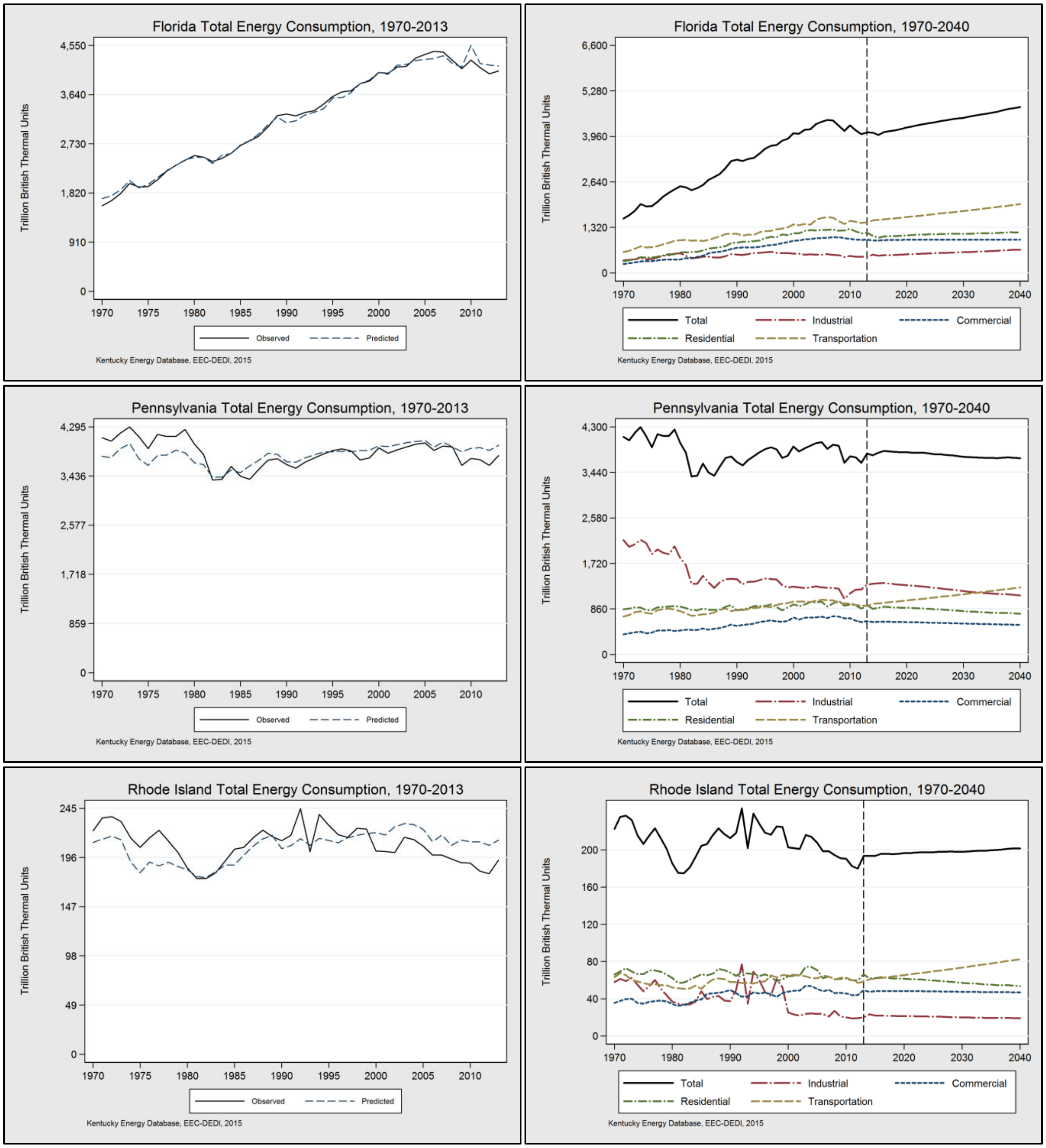


Figure 14 (Continued): State Validation and Forecast Graphs

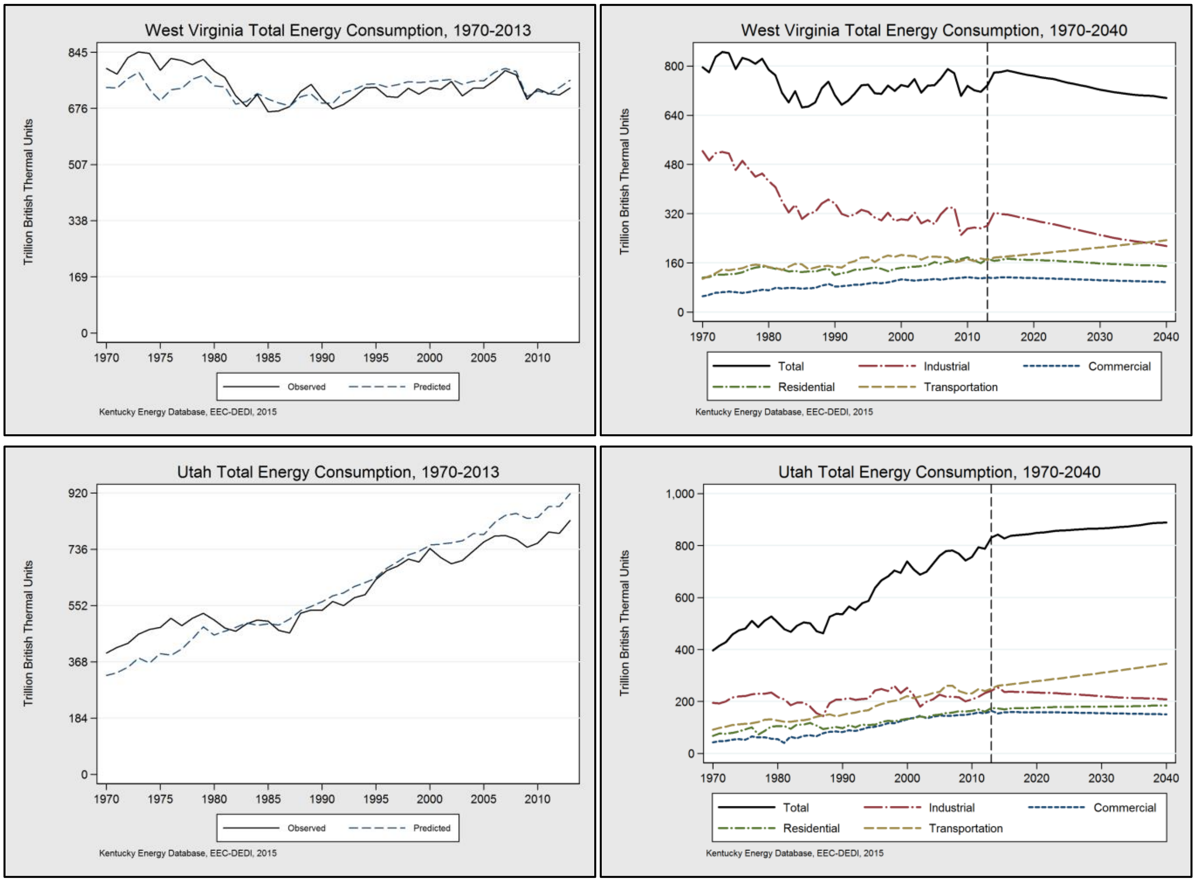


Table 3: Sectoral and Total Absolute Mean Errors Using Historical Data

		Commercial	Industrial	Residential	Transportation	Total
	Mean	±5%	±9%	±4%	±4%	±4%
Errors Less than	**±1%**	17%	8%	17%	19%	18%
	±5%	65%	17%	66%	75%	71%
	±10%	91%	68%	91%	97%	93%
	±20%	99%	90%	99%	100%	99%

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